

Science Fair: Clarity of Thought in Independent Experimentation

A successful science project can be one of the most rewarding and memorable experiences in the junior high student's career. Ideally it brings the power of the scientific method to bear upon a point of interest in the student's own world. This step-by-step method shepherds young scientists through the daunting thickets of experimental research. It provides clear guidance through a five month process of exploration, discovery, choice, experimentation, analysis and display. Not only do students come to a first-hand appreciation for the sound rational basis of the scientific method, but they also grow through the trials and triumphs of devising and executing a long-term project.

Timeline for Science Investigation

September

In class modeling of scientific method. Possible projects include: Mousetrap Catapult with 20 trials for 3 different launch particles, Helicopter design, effects of gibberellic acid on bean plant growth, etc...Teaching of statistical analysis (see below).

Investigation includes a detailed log of time spent on the project in a self-reflective journal. At least twice a week, students record what they did for the investigation and time spent doing it. They record their thoughts, questions, and observations related to the experiment. This is meant to be a paper pathway following thoughts about the topic through time.

Begin journal entries on time spent/activities performed/thoughts/ideas (mandatory two entries per week).

October

Develop ideas to include questions and hypotheses (use of grid). Select your study topic. Conduct background research (day at UCSB library). Prepare interview questions for an expert in the field and conduct interview.

Develop experimental design and start to gather/make materials.

November

Conduct experiment/start collecting data.

December

Continue to conduct experiment/collect data.

January

Analyze data.

February

Make conclusions. Look for practical applications, adjustments to procedure to improve it, discuss problems encountered.

March

Display project for possible entry to county science fair. Practice for interviewing.

April

Share projects with members of the school community as appropriate.

Sequence by Day

Day 1: Class goes outside to observe nature with hand lenses. Students write down 10 specific observations of the world around them. Back inside the classroom, students change the observations into questions. (Ex: "Ants are crawling along a concrete edge" becomes "Why are ants crawling along an edge? What makes them follow each other? How do they know where to go? Does the surface texture affect an ants' ability to follow a path? Etc).

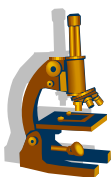
Day 2: Students share 2 observations & the questions generated with the class. Teacher gives many examples of previous science projects and emphasizes the importance of choosing a topic the student finds very interesting. Questions evolve from interest.

Day 3: Science book browsing in the library to spark ideas. Students have the opportunity to look through a huge selection of science books laid out on display in the library; they flip through them and discover more about what interests them. Students begin to write down what topics interest them.

Day 4: More time in library; students complete the list of 5 topics they find interesting. Teacher collects their list of 5 topics and gives feedback on whether the topic would be very difficult for a science project. Students decide on one particular idea.

Day 5: After teacher feedback (overnight or a week), research begins! Choose one topic. Begin background research. Teacher demonstrates appropriate use of resources, note-taking, attribution in MLA format. Students learn to write notecards and write in composition notebook. Science teacher can coordinate with GATE English teacher, computer lab for online research, and librarian as needed. This research paper can be dual credit for both English and Science, since students are required to do a research paper in English anyway, and most English teachers will let them use this science paper as long as they follow the English teacher's guidelines.

Allow 4 weeks for background research paper. During this time the teacher instructs students on the other content areas of physical science during class, but generally does not assign homework other than to work on the research paper. Of critical importance is a parent note with signature recognizing the presence of a long-term project that needs good time management. Teacher periodically does status checks, entered as grades in gradebook.



Science & English
Investigation Research Paper (GATE)

Due to Science Teacher for grading on _____ Due to English Teacher for grading on _____

What the science teachers expect:

* 4-7 pages of text that is 12 point Times Roman font, double spaced, 1.25 inch margins. Use a cover sheet for the title, as shown in English class.

* 20 or more note cards with proper source citation; sources should include at least one each from the following: encyclopedia, magazines & journals, newspapers, and books. An interview with an expert in the field is **STRONGLY** encouraged (extra points for this!) Sources from radio or video are also welcome as long as they are clearly cited.

* careful, logical thinking that clearly and thoroughly explores your subject of interest.

What the English teacher expects:

* Your English teacher will tell you in class! (*Great writing.*)

The Plan:

You write the research paper using your best intelligent ideas and most profound thoughts for the science teachers. Later, you will rewrite the paper with the same ideas, only using better language skills, for the English teacher. You will then use your beautifully written, well-researched paper as your background research report to be included with your science project that is due in March. This background research will give you a better understanding of your independent science investigation project.

Topics in the research paper should include:

An overview (at the level of a junior high science textbook) that explains the general field of interest that guided you to the topic you are studying.

More detail of what you are investigating, specifically. Has your experiment been tried before? What were the results? Are you modifying the experiment in some new way, or are you trying to confirm previous results?

What is already known about your specific topic, at about a 9th -10th grade level of understanding (a little harder than your textbook, as from a high school textbook).

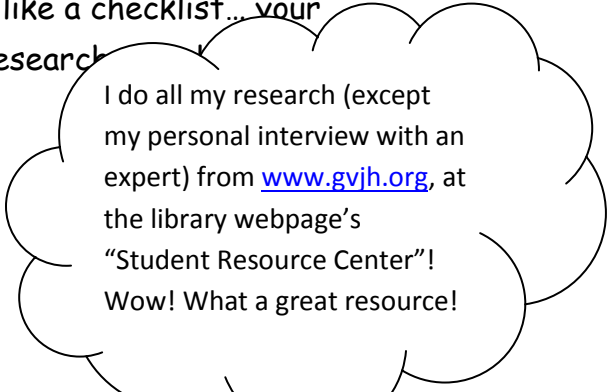
Some ideas to consider for writing:

- How does matter at the atomic/molecular level affect your experiment? Do electrostatic forces affect the situation? Should you study the matter at microscopic (but larger than atomic) scales of size? What is the structure of the matter?
- Complete analysis of physical and chemical properties of any materials involved.

- What kinds of energy are involved in your investigation, and in what form (kinetic, potential, radiative, chemical, etc)? How does that affect your subject?

- How does energy flow (transfer) through the system?
- Tell us about the instruments, if any, used to collect data. How do they work, how are they made, what are their sources of uncontrollable variation (error)? Could better instruments be invented in the future to study this topic?
- Is there a clear cause /effect relation involved in your topic of study? Why?
- Are there any equations that describe relationships among the variables of your experiment? (You may discover this by doing your experiment, or maybe they are already known.)
- Are there social implications of the situation you are studying?
- How is this knowledge used in society today? In the past?
- Are there industrial / technological / commercial applications?
- Does your topic of interest have potential applications that would help solve social or environmental problems today?

Any one of the above prompts could trigger a more detailed analysis and study for your research paper. Please do not go through these like a checklist... your particular project may require that you focus your research on these ideas.



I do all my research (except my personal interview with an expert) from www.gvjh.org, at the library webpage's "Student Resource Center"! Wow! What a great resource!

Timeline: Date

Day 1 _____ Write 2 notecards

Day 2 _____ Write 2 notecards

Day 3 _____ Write 2 notecards

Day 4 _____ Write 2 notecards

Day 5 _____ Write 2 notecards

Day 6 _____ Write 2 notecards

Day 7 _____ Write 2 notecards

Day 8 _____ Write 2 notecards

Day 9 _____ Write 1 paragraph

Day 10 _____ Write 1 paragraph

Day 11 _____ Write 1 paragraph

Day 12 _____ Write 1 paragraph

Day 13 _____ Write 1 paragraph

Day 14 _____ Write 1 paragraph

Day 15 _____ Write 1 paragraph

Day 16 _____ Write 1 paragraph

Day 17 _____ Write 1 paragraph



I have read the above research paper project timeline. I will help my student reach these goals on time each night, to avoid procrastination. I know the paper is due on _____.

_____ (parent signature).

Student Name:

Day 6: Teacher and students discuss rigorous control of variables in experimental design. Students design their own original experiment, stating their hypothesis, materials, procedure, what they will measure, and how each detailed aspect of the experiment will control for unintended variation. Teacher should collect, study, and give feedback to students for final approval of project. No one should begin an experiment without approval of the teacher.

Days 7 - 13: Data Analysis (refer to students' math books for sample problems and instruction examples as needed)

Day 7: Teacher reviews the three measures of central tendency (mean, median, and mode) and teaches as needed. Instruction is given on percent difference statements: "X is N percent greater (less) than Y" means that Y is the number that is the "original amount" for the percent difference proportion:

$$\text{Amount of change} / \text{Original amount} = N / 100$$

We also review how to solve a proportion using the mathematically correct procedures (no short cuts!) of setting cross products equal to each other, then multiplying by the multiplicative inverse of N's coefficient. Do many practice problems! The goal is for students to be able to look at their control and experimental results and state: "The mean for the experimental group was N percent larger/smaller than the mean for the control group."

Day 8: Teacher reviews how to construct a box and whisker plot (refer to 7th grade math books for lessons as needed). Using second and third page of the "Statistical Analysis" handout, students review the definition of Interquartile Range, Outlier, etc. Teacher should tailor the instruction to the needs of the student group. Point out that there are instructions on the internet for how to make a box and whisker plot on Excel.

Days 9 - 10: Teach how to find standard deviation as a measure of data spread. The handout is only a review guide... the actual instruction should initially come from the teacher. I emphasize that we are trying to find a sort of "average distance from the mean" - but by squaring, then finding square root.

Handout Available for Download: Statistical Analysis

Note: The word "data" is plural. "Datum" is the singular form. "The data show that..." is correct, NOT "The data shows that..."

Is the central tendency of data the only thing to describe?

No, we might want to describe the variance of the data - how much they deviate from the center point. What is the shape of this graph? Is it a gradual slope that is spread wide around the mean, or does the shape of the graph rise steeply, with most of the data clustered around the mean?

The two graphs show the same mean but with data spread out differently. The way we measure spread is with the number called the "standard deviation," which tells you how far your data points have spread away from the mean. It's sometimes called the "root-mean-square": the square root of the mean squared deviation of a quantity from a given baseline (usually the mean of your data). Yeah, right. Okay, let's try again:

1. First, find how much all your data points are different from the mean.

(Take each of your numbers and subtract the mean from them, one at a time, so you have a bunch of differences from the mean.)

2. Second, square all these differences. (SQUARE)

(Why? Because the ones below the mean are negative, and above the mean are positive, and they would just cancel out if you added them together and that would eliminate any hope of finding how far the numbers are from the mean.)

3. Now, add up all the differences and divide by the number of data points you had. (MEAN)

4. Lastly, take the square root of that number. (ROOT) This way you get back a reasonable-sized number that works in your data, and is not too big like the squares would have been.

Putting it all together, you have just found the ROOT-MEAN-SQUARE, or standard deviation.

The formula:

$$S = \sqrt{\frac{1}{n} \sum (x_i - \bar{x})^2}$$

where n = number of data points, x_i is any one particular datum,
and \bar{x} is the mean of all the data.

Please be aware that the standard deviation can be found differently for different situations. We are giving this formula for the case when you have all the data for a certain population. On Microsoft Excel, the formula command is "stdevp(cell:cell)", the "p" standing for "population". The formula is slightly different if you are taking a sample from a larger population and estimating the standard deviation from that sample.

Special notes:

Standard deviation should only be used when the mean is chosen as the measure of center. Outliers in the data will strongly influence the standard deviation. Do not use this if your data is very skewed because the spread will be very different on left and right.

One helpful use of standard deviation is that for a "normal" distribution (meaning a bell curve), approximately two-thirds of the data will lie in between the standard deviation above the mean (\bar{x}) and the standard deviation below the mean.

$$(\bar{x} + s) - (\bar{x} - s) = \frac{2}{3} \text{ of the data.}$$

Analysis Chart

Basic analysis of numerical data includes finding the mean, median, or mode (whichever measure of central tendency is most appropriate for your data), the upper and lower extremes, and computing the percentage difference between the mean or medians of variables being compared. More advanced would be to include the standard deviation and a description of the spread, or general shape, of the data when graphed.

A good way to show both the central tendency and the spread of the data is to create a chart showing:

Minimum Q1 Median (Q2) Q3 Maximum St. Dev.

Graphs

Hopefully the graph will be able to relate the independent variable (X - what you changed, on the horizontal axis) and the dependent variable (Y - what you measured as an effect, on the vertical axis). Note that sometimes you can make a nice connection between your hypothesis and the graph: "If I change X, then I can measure a trend in Y."

A viewer of your display should be able to make a quick connection between your hypothesis and your graph.

When you are displaying your data, you might wish to use a stem plot and a box and whisker plot. Stem plots, like histograms, quickly show if your data clusters around a set of numbers. You can use stem plots to show two sets of data like this:

Box and whisker plots are especially helpful for quickly giving the viewer a comparison of two or more groups of data. For example, if you were comparing the math test scores of different groups of people, each group of people would be its own box and whisker plot on a common scale for all:

Note that in box and whisker plots, exactly one fourth of all the data points are in each section. Therefore, box and whisker plots quickly tell you where half the data lie. (In the interquartile range, the "box".) They also tell you the median and whether the data is evenly distributed around the median or if it is skewed higher or lower. This can be valuable for quick visual comparison. You can also describe the way the data is clustered in your written analysis.

Box and whisker plots also enable you to define whether you have an outlier in your data or not. You can tell if one of the extremes is an outlier by multiplying the interquartile range (the third quartile, Q_3 , minus the first quartile, Q_1) by 1.5. Let's call that number "a". If your datum in question is $< Q_1 - a$, or is $> Q_3 + a$, then

it is an outlier and could be legitimately thrown out of the data for calculation of the mean.

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What if the data is not numbers, but just a record of how many responses are in particular groups? For example, "10 people like dogs while 14 people like cats" cannot be analyzed with mean, median, standard deviation, etc. In this case you would present the data in a bar chart and a pie chart, and calculate the percent differences between the quantities.

Analysis of data includes:

1. Is there a positive, negative, or no correlation between the dependent and independent variables in the experiment? State evidence to support this conclusion.

Scatter plot is good for this

Curve/line of best fit type graph also works

2. What is the central tendency of the data? Which measure of central tendency is most appropriate to use for this situation?

Mean

Median

Mode

3. Calculate whether outliers exist in the data. (I think the calculation is as follows: the quantity $(Q3 - Q1) \times 1.5$ above or below the mean is considered an outlier. Do outliers affect the validity of the measure for central tendency? Should they be ignored in calculation of the mean?
4. Measure the spread of the data. Two ways: standard deviation and box and whisker plot. Box and whisker is good because it quickly shows the way the data clusters.
5. Measure the significance of the experimental results as compared to the control. Use T-tests and chi-squared, as deemed relevant. Only use tests that you understand!
6. In addition to charts and graphs, include a written interpretation of your analysis (this interpretation should not be conclusions which are inferences based on your data analysis).

Day 11: Equations of Best Fit

Review linear, quadratic, & exponential general forms. Depending on the class, the teacher might have students plot points that will generally fit one of these general forms. Teacher then demonstrates how to visually sketch a "curve of best fit", and then demonstrates how Excel does this with the "make trendline" command. Discuss precision vs. accuracy of constants in Excel's produced equations.

On a more basic level, review slope of linear equations and y-intercept. Given a line on a coordinate grid, each student should be able to determine the equation of the line.

Apply this to their science project results. If the dependent variable (what they measure in the experiment, plotted on the y axis) is plotted in an XY coordinate grid against the independent variable (what they changed in the experiment; the experimental variable, plotted on the x axis), does the resulting plot of points demonstrate a correlation or no correlation? Do the data indicate a positive or negative correlation between the experimental variable and the measured effect?

Using the equation of best fit, students should be able to make a general statement describing the relationship between their experimental variable and measured effect. For example, "The amount of leaf growth is 1.5 times the amount of fertilizer added"; "The increase in power is roughly equal to twice the increase in fuel, subtracted by 3"; "The force on the patellar tendon is 1.4 times the angle of the knee".

Day 12: Teacher gives a sample of data from a project similar to what the students might have for their own data sets. Teacher asks the open-ended question: "What can you say about this data?". Probably no-one responds; so give students 2 minutes to brainstorm on paper some ways they could describe the data. Do a think-pair-share; hopefully some students will come up with tools of analysis we've been studying. After sharing what is expected (mean, median, mode, box and whisker, standard deviation, equation of best fit, percent differences between the means, etc), have students work in partners to write an analysis paragraph following a cloze example. (Analysis paragraph example included for download)

Day 13: Quiz on data analysis. (Teacher should make own suitable for the group.) Show students the Santa Barbara County Science Fair website & California State Science Fair website, & discuss Project Components of a good science fair project.

Days 14 - 16; must be 3 consecutive days; best done sometime before the Martin Luther King, Jr. holiday in January.)

***Meet Me on the Front of the Bus:
the Strength of Non-Violence***

Often the most fulfilling learning experiences combine heart and mind. This demonstration in social science brings together high tech polling and data analysis with the visceral subject matter of 1960's Civil Rights protests. Data gathering tools are turned toward the students themselves, as they become subjects for

opinion gathering and analysis. At one level, this is an experiential lesson on the limits and possibilities of social science. At the same time, a philosophical door is opened to critically compare moral vs. physical strength in the context of social reform. Is violence always effective in changing the minds of others? What makes non-violent change compelling and plausible?

Lesson Objectives: Through simulation, students will debate the merits of taking a moral stand during non-violent civil rights protests of 1961, particularly the lunch-counter boycotts of Nashville and the Freedom Ride. Students will also define what makes a good social science experiment, and use data generated from a before / after quiz of their views on the efficacy of non-violent social action to analyze and interpret data.

Content Standards:

Science

9b. Evaluate the accuracy and reproducibility of data.

9e Construct appropriate graphs from data and develop quantitative statements about the relationships between variables.

Materials/Technology Needed:*

- Class set of Interwrite PRS-RF remotes
- Computer with Microsoft Powerpoint, Excel, and Interwrite plug-in for PRS installed into Excel.
- LCD display projector for computer
- Powerpoint lesson I've included for download - you should modify it as needed to suit the video clips available to you
- "Eyes on the Prize" video of student lunch counter sit-ins and freedom ride

***Without the technology, a teacher could simply give a well-planned quiz before / during / after the video and presentation on non-violence, then manually tally the results later. The essence of the lesson would be the same.**

Procedures/Activities:

(This lesson presupposes a knowledge of mean, standard deviation, and how to write an analysis paragraph for a science experiment. It is best done before students

have school-wide or social studies presentations on Martin Luther King or non-violent civil disobedience.)

Day 14

At the beginning of the powerpoint slide show, students are polled on their attitudes about non-violence. Their responses are NOT displayed in graphical form during this first survey.

Teacher gives brief introduction to historical context of the student lunch counter sit-ins, and introduces the people in the video clips (especially Diane Nash & Jim Lawson, terms such as NAACP, segregation, anything that my students will be unfamiliar with that is referred to in the video). Class then watches video clip of the training for non-violent protests at the lunch counters. Teacher pauses video when the police show up and are about to arrest the students at the counters. Teacher asks, "Who is arrested?", and class polls their response. Class views their own graphical results on the display, then we watch the video and discover that the police did not arrest the aggressors, but the people sitting at the counters.

Video then goes to the freedom riders, and again, teacher pauses the video just after students see the mob surrounding the bus and hear the man describing the riders' dilemma: should they get off the back of the bus or the front? Students are polled, we see their results, and students are asked to give reasons why they voted the way they did. Then we watch the rest of the video and discover that the riders did decide to go off the front.

Teacher then shares Martin Luther King, Jr.'s Six Principles of Nonviolence, (download available on this site) and students receive a handout with those principles. They are asked to share them with their parents to see what the parents think about these ideas.

Day 15

Students take the survey on their attitudes toward bravery and non-violence again. Their responses are displayed graphically and can be used as a point of discussion: "Why do you think people who voted this way did so?"

The teacher presents the "before the lesson" vs. "after the lesson" results for one question on attitudes about non-violence. Teacher demonstrates how Excel can be used to find mean and standard deviation. Using these numbers, students

determine the percent difference in the before/after results.

Teacher then poses the question: "What is missing from this experiment that is absolutely essential in a real experiment?" Students will eventually respond that there was no control group. Teacher asks, "What would a researcher have to do to get an accurate control group?" This should lead to a fruitful discussion of uncontrollable variables in this experiment and how one could design a social science experiment in real life.

At this point, teacher gives out "imaginary" data. Teacher explains to students that since we have now discovered what we would have done in the real world to create a good experiment, we will now pretend we did that, and got the results presented by the teacher. Given this hypothetical situation, students are asked to brainstorm, then write a "Discussion" section of a science fair project using the data from yesterday's simulation.

Homework is for students to analyze the "control" and "experimental" data groups, and to write an analysis paragraph following the example of the cloze Analysis paragraph.

Day 16: Review student's work from yesterday. This is important processing time to clarify what goes in a discussion, conclusion, and analysis.

Day 17: Project critique: In groups of 6, students rotate around the classroom to 5 different stations. Each location displays an outstanding project from previous years, and asks students to evaluate the projects with respect to various criteria that the teacher thinks the group needs to focus on to achieve excellence. (Usual areas of weakness are clarity of analysis, breadth and depth of discussion including possible sources of error, simple & clean presentation of hypothesis - results - conclusion).

Day 18: Go over Project Grading Rubric and answer questions on the Project Components handout. Each student takes home the grading rubric and Project components handout to help them focus their efforts at home.

(after a few weeks, students turn in projects)

Day 19: Students evaluate a partner's work using the criteria of the grading rubric. Students may revise projects to incorporate feedback from partner before turning in for grading.

Days 20 – 21: Students give a brief presentation, + question/answer session to the class on their project.

Assessment and Evaluation

Quizzes, collect and grade homework and analysis paragraph as needed, and Grading Rubric (available for download)

Resources

- Class set of hand lenses
- Class set of Interwrite PRS-RF remotes
- Computer with Microsoft Powerpoint, Excel, and Interwrite plug-in for PRS installed into Powerpoint
- LCD display projector for computer
- Selected Excerpts from Video: "Eyes on the Prize: America's Civil Rights Movement", total 24 minutes.
- Class will use the school library's resources and online Student Resource Center (Gale Resource Group) if their school has this internet resource.
- Each student will need a composition notebook (lab notebook), binder, and science fair display board, and access to a computer and printer for producing their graphs.

Available for download here:

- Independent Research Paper Guidelines
- Analysis paragraph example - should be done before lesson, and used by students as a guide for their own paragraph they will write.
- Powerpoint slide show with embedded PRS response
- Science Fair Project Grading Rubric

